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Cost Versus Risk: The Policy of Nuclear Weapon Maintenance of Tritium Based Limited Life Components

Michael P. Mason

COST VERSUS RISK:
THE POLICY OF NUCLEAR WEAPON MAINTENANCE OF TRITIUM BASED LIMITED LIFE COMPONENTS

THESIS

MARCH 2017

Michael P. Mason, Captain, USAF

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DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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Michael P. Mason, BS
Captain, USAF

Committee Membership:

Alan W. Johnson, PhD
Chair

Paul L. Hartman, PhD
Member

Carl R. Parson, PhD
Member

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Abstract

This research develops a method to measure the cost to society of current maintenance policy for the exchange of tritium based limited life components within nuclear weapons. The incentives for the Department of Energy and Department of Defense which causes either a substantial cost or substantial risk to be accepted by either Department. A simulation model is created to measure the current policy and compare it to different policies in order to recommend a policy that would minimize the cost to society. The measurement of the cost to society will offer decision makers insight into the ramifications of their decisions.

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COST VERSUS RISK: THE POLICY OF NUCLEAR WEAPON MAINTENANCE
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I. Introduction

Overview

In the 2010 Nuclear Posture Review Report prepared by the Department of Defense (DoD) and submitted to Congress, Secretary of Defense Gates, with direction from President Obama and the Secretaries of State and Energy, pledged that "as long as nuclear weapons exist, the United States will sustain safe, secure, and effective nuclear forces. These nuclear forces will continue to play an essential role in deterring potential adversaries and reassuring allies and partners around the world" (Department of Defense, 2010). The DoD along with the Department of Energy (DOE) must consider the high cost and extended timelines needed in order to sustain the nuclear arsenal (Department of Energy, 2013). Currently, the DoD annually spends $8-9 billion on the nuclear triad, but this number does not account for the entire cost of the arsenal. The DOE spends over $11 billion annually for weapons activities not including the cost of follow on replacement weapon systems (Wolfsthal, Lewis, & Quint, 2014). The combined costs to the DOE and DoD is important to investigate because while one department may fund installation of a component, the other department could be responsible for supplying the component. Due to the conflicting missions and objectives of each department, a dilemma may occur. The $19 billion in weapon activities only includes direct expenditure on the sustainment of the weapons themselves and does not encompass the full gravity of the cost placed on tax payers of the massive Nuclear Security Enterprise that must be maintained and advanced in order to keep up with demand.

This paper discusses the potential for the DoD, specifically the Air Force, to save limited resources by scheduling nuclear weapons maintenance in a manner that maximizes the service life of the weapons and their various components which require replacement. The Air Force may be able to reduce the strain on the supply chain for high dollar replacement parts. This ability could not only save the DoD and DOE money but also reduce the number of maintenance procedures performed on a weapon, increasing the reliability of the weapon.

Background

Nuclear Stockpile

In 1992 the United States voluntarily enacted policy that prohibited underground nuclear testing (Nikitin, 2016). The prohibition of underground testing resulted in the suspension of new untested nuclear weapon designs (Perry, Scowcroft, & Ferguson, 2009). This new initiative counter acted how nuclear weapons were designed from the 1960s to the 1990s. Previously, nuclear weapons were designed to be replaced by a new design and entirely new weapon system at the end of their life cycle (Royal, 2015). The suspension of new weapon designs led the United States to keep current weapon designs and later would eliminate the production of new weapons entirely. Because no new weapons were developed, current weapons are relied on for the future of the stockpile which fosters a greater risk of an entire delivery platform being placed offline because of a catastrophic failure of one of the weapon components. A failure in a weapon component would ground a weapon system with no replacement being capable of being developed or produced (Deputy Assistant Secretary of Defense Nuclear Matters, 2016).

Nuclear weapons have been able to be maintained and certified as safe and reliable even through the end of nuclear testing in 1992 via the Stockpile Stewardship Program. Reliability becomes a bigger challenge the longer these weapons remain within the stockpile without replacement. The current Stockpile Stewardship Program includes maintaining the active stockpile, life extension programs (LEPs), and weapon dismantlement (National Nuclear

Security Administration, 2016). While different weapon systems are at different stages along their life cycle within the arsenal, they all have one commonality, they must all undergo periodic maintenance in order to stay active. While the United States' stockpile of 4,717 warheads, as of September 2014, is a substantial reduction from the height of the national nuclear stockpile of 31,255 weapons seen in Figure 1, the weapons that remain must be kept safe, secure, and reliable (State Department, 2015).

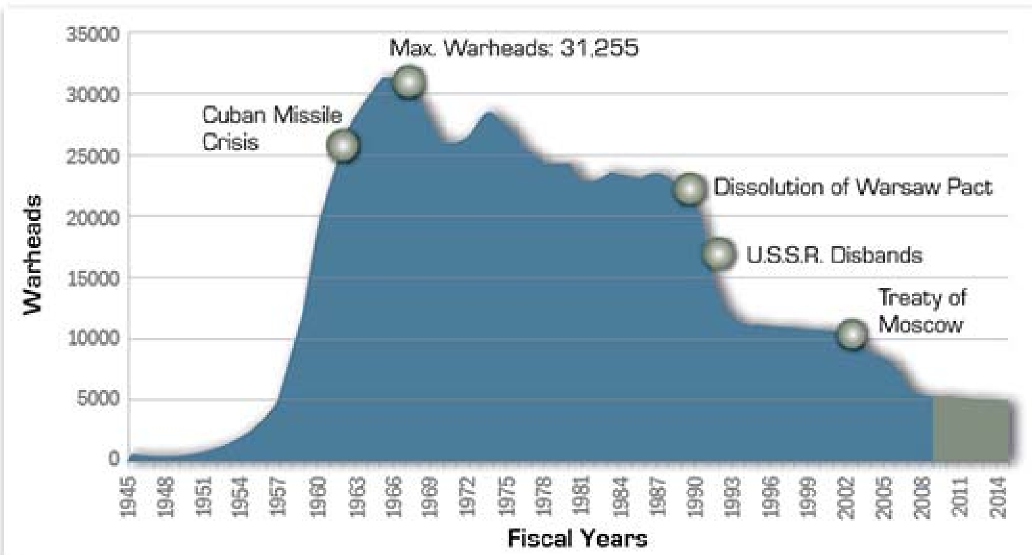


Figure 1: Stockpile Quantities *(Deputy Assistant Secretary of Defense Nuclear Matters, 2016)*

Nuclear weapons within the United States' stockpile are kept in three different configurations: active, inactive, and retired. Active weapons are kept in an operational status with Limited Life Components (LLCs) installed and maintained on the warhead. Inactive weapons are non-operational warheads that do not require having LLCs installed on them and the weapons that have LLCs installed are frequently removed through attrition of the components or dictated by policy. These active weapons are capped by the New Strategic Arms Reduction Treaty (START). This treaty restricts the U.S. and Russian nuclear forces to 1,550 operationally deployed strategic nuclear weapons on no more than 800 deployed intercontinental ballistic missiles (ICBM), sub-launch ballistic missiles (SLBM), and bombers by February 5, 2018 (U.S. and Russian Federation, 2010). Inactive weapons are maintained and kept in a ready state configuration which serve multiple purposes, such as logistical spares, as a hedge warhead that can be made active within a certain prescribed timeline, or stored as inactive in case of a technical failure in a different weapon system (Wood, 2016). Retired weapons are warheads that are stored without LLCs installed and are awaiting dismantlement. They are kept in this stage either awaiting to be dismantled or awaiting to be approved for disassembly, called managed retired. All retired warheads must be maintained in a status that could allow the weapon to be reactivated in the event of a major failure in one of the other active or inactive weapon systems while in the custody of the DoD (Deputy Assistant Secretary of Defense Nuclear Matters, 2016). The difference between the two being that managed retired weapons have not been fully approved for disassembly and a new mission or new Life Extension Program (LEP), discussed next, could require the weapon to be brought back into the active/inactive stockpile (Deputy Assistant Secretary of Defense Nuclear Matters, 2016).

The United States has not developed or produced a new nuclear weapon since 1992; because of this, the current stockpile undergoes a LEP with the intent of updating the weapon without producing a new nuclear package. The LEP will update components within the weapon and prepare the weapon system for the future, but the design of the nuclear package will be maintained, including the radioactive pit and explosives surrounding the core (Department of Defense, 2010). The weapon system, before or after LEP, will still require periodic maintenance to replace LLCs within the weapon.

Limited Life Components

LLCs are items within nuclear weapons that must be replaced in accordance with a predetermined time interval (Department of Energy, 2015). These components are used to perform a certain function within the weapon and if the component does not perform up to a certain level of potency or reliability the weapon will not function as designed. These time requirements are based on the required reliability or design of the weapon system and the decay of the component in question. LLCs can take the form of Neutron Generators, Power Supplies, or Tritium Bottles, to name a few. This research is limited to only reviewing tritium reservoirs. The methods and results of the research can be extended to other LLCs but further analysis and data are required. All LLCs are exchanged prior to expiration date, unless an abnormal condition exists, so that the weapon is always maintained in a state of readiness within the active stockpile. Limited Life Component Exchanges (LLCEs) are conducted by Navy and Air Force Technicians at appropriate military installations (Deputy Assistant Secretary of Defense Nuclear Matters, 2016). The weapons are maintained according to their level of need, depending on their status of active or inactive, and follow the schedule that is developed for each warhead by the Department of Energy (DOE), specifically the National Nuclear Security Agency (NNSA) through coordination with the appropriate military service.

An LLC has an intended function within the nuclear weapon design and it must perform its function with a certain degree of confidence and/or potency that is well calculated. The potency becomes an issue because most of the LLCs are designed with a radioactive element within them. These bottles are used for boosting the weapons and have the effect of multiplying the yield of the weapon which allows the weapon design to limit the required quantity of fusionable material within the weapon. The ability to boost weapons was a major development within the U.S. nuclear stockpile and allowed the U.S. to build smaller and a greater number of weapons (MacKenzie & Spinardi, 1995). Tritium itself is a radioactive form of hydrogen and decays at a rate of 5.5% each year. This decay requires that the tritium within the bottles be replenished in order to maintain a certain degree of confidence that the weapon will perform as designed (Savannah River Site, 2011). If a tritium bottle is not exchanged by its prescribed expiration time, the weapon would produce a yield less than its performance requirement (Deputy Assistant Secretary of Defense Nuclear Matters, 2016). The same concept applies to other LLCs, as they operate via some radioactive or explosive element that decays over time. Although this research will focus on tritium reservoirs, the basic principles found in this research can be applied to other LLCs. The decay rate in each LLC is known and accounted for when calculating the life cycle of each LLC. While the specific life cycle of each component is classified, the Nuclear Matters Handbook created by the Office of the Secretary of Defense states "These weapons undergo regular replacement of LLCs, usually at intervals of a few years" (Deputy Assistant Secretary of Defense Nuclear Matters, 2016). This research will look at a range of years from replacement at one to five years with intervals of one year but does not address any specific weapons system or any specific tritium reservoir.

Maintenance of Nuclear Weapons

Specific Air Force units throughout the world are certified and authorized to store and maintain nuclear weapons. These units work closely with the NNSA to coordinate parts, technical orders, logistics, and guidance when needed. This relationship has always been strong out of necessity from the original declaration in the Atomic Energy Act of 1946 that nuclear weapon development and technology will be under civilian control and not controlled by the military (79th Congress, 1946). The civilian control has changed through time but the fact has remained that all nuclear weapons are owned by civilian oversight instead of military oversight (Feaver, 1992). This control has been adopted to the present time where the ownership is held within the NNSA and not with the military. The Air Force provides the trained personnel and facilities for maintenance actions to take place as well as schedules alongside the NNSA to forecast the need for the LLCs which are produced at sites controlled by the NNSA. The Savannah River Site, for example, recycles used parts to try and salvage as much as possible for future components. The NNSA controls the schedule of production of the Limited Life Components but utilizes the inputs from the Air Force on when the maintenance actions could take place.

As a weapon approaches the expiration date, the weapon will be placed on a long-range schedule which includes a projection of maintenance dates out one fiscal year. This long-term schedule is submitted by the unit no later than 1 February the fiscal year prior (Secretary of the Air Force, 2015). This long-range schedule is developed by the Air Force unit who will perform the maintenance actions taking many variables into consideration when scheduling the maintenance action including Air Force policy on the timing of the maintenance action. This long-range schedule is used as a forecasting tool for the DOE/NNSA to determine the demand placed on the supply chain (Secretary of the Air Force, 2015). DOE/NNSA will alter their production schedule of the different LLCs to best match the demand of the Air Force's long-range schedule (Savannah River Nuclear Solutions, 2013). Once the components are produced by DOE/NNSA the life cycle for that specific component has started and the expiration date is known. If for example, a tritium bottle is filled in March, the timeframe for when that bottle will expire is fixed given the tritium decay rate of 5.5% a year. The tritium bottle will now have some expiration date that is based on the fill date of the tritium and not based on the date of the maintenance actions performed by the Air Force unit.

Nuclear weapon maintenance is solely based on the principle of proactive maintenance. The LLCs within the weapon have a known rate of decay. This rate of decay is used to calculate the time at which the component will not be able to perform to the level required. The date at which the component must be exchanged becomes the due date. The due date is set per the planners within the DOE/NNSA and it becomes the job of the DoD unit to forecast on the long-range schedule when the maintenance will be accomplished (Deputy Assistant Secretary of Defense Nuclear Matters, 2016). Once the DoD has forecasted the maintenance, DOE/NNSA is informed of the date with the intent to schedule the delivery of the new replacement component (Secretary of the Air Force, 2015). Within the Air Force, the forecasted maintenance action may not be the day of execution of the assigned task. Many variables are taken into consideration with many variables unknown a year prior to the date of the maintenance. Maintenance managers must be proficient enough to forecast their constraints, but actual maintenance completion often varies from the long-range schedule.

Research Objectives, Hypotheses, & Investigative Questions

The objective of this research is to examine current long-range policy for scheduling LLC maintenance, evaluate the cost and risk the current process invokes, and analyze the impact potential policy changes will have toward minimizing cost and risk. As the due date for the LLC approaches, having an accurate way to measure the risk in scheduling the exchange closer to the due date allows maintenance managers and stockpile planners to be able to use as much of the life of the component as possible while minimizing the risk of the component surpassing its expiration date. By utilizing the complete life of the component, the cost of maintaining the stockpile with replacement components will be reduced by reducing the frequency of maintenance actions, the supply chain strain will be reduced, and the associated risk becomes more predictable.

Motivation

The motivation for this research is to give maintenance managers the full picture of implications when scheduling maintenance. If the maintenance manager does not understand the full implications of scheduling the component early and only understands the benefits, the maintenance actions will be scheduled at the earliest possible moment to ensure the actions are complete. The DoD may not be incentivized, in the short term, to utilize the entire life of components but instead have the desire to perform LLCEs well in advance of the expiration date. Maintenance and stockpile managers should be aware of the ramifications that actions and policy can have on the nuclear security enterprise supply chain and the potential misuse of scarce resources.

II. Literature Review

Proactive Maintenance

Proactive maintenance includes two general maintenance practices, preventive and predictive, and is covered broadly throughout academic research. Proactive maintenance is performed when a high reliability of the system is desired and a higher availability of the system's function is needed. Proactive maintenance provides a higher rate of availability of the system because as the scheduled maintenance occurs, all scheduled components are exchanged, without failure of the component, compared to reactive maintenance which only replaces a component upon failure. Figure 2 compares proactive to reactive maintenance (Wessels, 2003). The reactive maintenance cycle conducts maintenance on a system once a failure occurs, only replacing the failed item making the system available again. Every reactive maintenance action only brings the availability of the system, plotted in Figure 2 as a dashed line, back to the previous availability prior to component failure. This is because as a part is replaced, other components are not replaced and their reliability is lower compared to new parts. A proactive maintenance schedule, shown as the solid line in Figure 2, accomplishes the maintenance per a periodic preventative schedule or based off a predictive diagnostic measurement (Ebeling, 2005). As Figure 2 demonstrates, the availability of the system under a reactive maintenance practice will decrease compared to that of a proactive maintenance practice for systems with increasing failure rates.

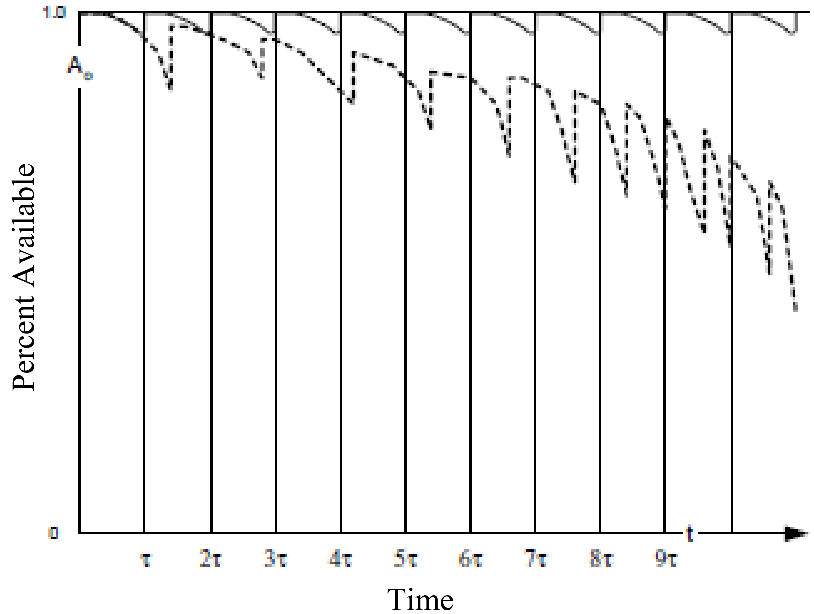


Figure 2: Proactive versus Reactive Availability (Wessels, 2003)

Proactive maintenance also has the benefit of eliminating the immediate strain placed on supply chain and administrative actions (Wessels, 2003). In a reactive maintenance practice, the failure of a part is not predicted nor changed periodically and the replacement part must be ordered through supply once the failure occurs. This can create a delay in the maintenance. Another delay of reactive maintenance is the administrative actions that need to be accomplished prior to maintenance (Ebeling, 2005). Administrative actions can include the scheduling of facilities, personnel, security, or purchasing capital needed to perform the maintenance. A reactive system would have to wait until the supply and administrative actions were complete prior to completing the maintenance. This leads to longer downtimes and reduced availability of the system. A proactive maintenance system forecasts supply and administrative needs allowing the components to be ordered just in time prior to maintenance. This reduces the downtime because of the known lead time for supply. Administrative actions can be forecasted as well which further reduces the down-time.

A downfall of proactive maintenance is the idea that earlier maintenance increases the availability of the system (Ebeling, 2005). If a maintenance manager has the ultimate desire to increase the system availability, the manager may be incentivized to schedule the maintenance actions earlier and earlier. The earlier a component is replaced the greater the entire system's availability is because degraded components are renewed, assuming perfect maintenance practices. As a system's scheduled maintenance becomes more robust, the availability of the system increases because fewer unexpected failures will presumably occur. This increase in availability can lead managers to conclude that a system should be frequently maintained. However, this is not necessarily the case because the system must usually be rendered non-operable while the maintenance is done, which itself serves to decrease availability. If the system was constantly in maintenance then the system could never be used and the availability of the system would be zero. Furthermore, when something is maintained it is typically not completely renewed because of cost and time constraints. Therefore, excessive maintenance degrades the system at some rate (Ebeling, 2005). Planners should seek the best overall balance between system cost, availability and scheduled maintenance actions.

Cost Based Preventative Maintenance

For a business to truly capitalize on a proactive maintenance strategy, the company must consider cost as well as system availability when developing a schedule. The goal for maintenance managers using Cost-Optimized Scheduled Maintenance Intervals is to realize the benefit of replacing components before failure at an interval which maximizes the utilization of the component within the system (Wessels, 2003). This assumes that predictive maintenance costs are less than corrective maintenance actions. This assumption is made because under a predictive maintenance policy, scheduled downtime is planned while unscheduled maintenance actions inflict variability into the system, greatly impacting unforeseen costs on the entire system. The high cost of corrective maintenance comes from the unknown for scheduling the maintenance. When a component fails, maintenance must respond with the actions, labor, and parts to correct the problem (Ebeling, 2005). The time that it takes for the actions, labor, and parts to respond to the failed component could cause delays which will extend the unscheduled downtime even further. Also, one unknown failure within a system could cause strain on the entire system and cause other components within the system to fail at a faster rate or put undue strain on the system. Preventive maintenance will allow managers to be able to know when labor and parts will be needed and to have essential items on hand at the time of the maintenance action.

The goal of scheduling the maintenance is to minimize the strain on the entire business because the downtime is to be expected and could be lined up with other maintenance downtimes (Wessels, 2003). The difficulty in scheduling preventive maintenance actions this way is knowing the true cost of the preventive maintenance versus the cost of corrective maintenance. A business would have to measure the cost of both maintenance practices and determine which method better utilized resources.

Just-In-Time Delivery/Toyota Production System

Just in time (JIT) delivery is a portion of the Toyota Production System (TPS) which has been studied throughout literature. JIT delivery within TPS uses a "kaban" method where the production system utilizes a pull system instead of a push system. The pull system takes parts and replenishes them only when needed and only in the right amount (Liker, 2004). JIT delivery reduces the inventory within the system and does not concentrate on the price per piece for a machine but instead looks at the entire system and only produces a part just prior to when it is needed. The intent behind JIT delivery is to “supply the right materials at the right time and in the right amount at every step in the process” (Tommelein & Li, 1999). Tommelein and Li used JIT delivery to show different alternatives for the delivery of concrete. Concrete is a unique product in that it is perishable with a short life cycle, has to meet customer needs, and the delivery must be met on time for the crews to be prepared. This research looked at the vertical supply integration alternatives that could reduce the risk incurred by late delivery of the ready to mix concrete. A late delivery will cause the concrete to expire and the concrete may not meet required specifications, as well as incur the high cost of the wasted time for a lay down crew with no delivery (Tommelein & Li, 1999). This research looked at the ability for a contractor to vertically integrate and own the delivery method from the concrete plant and compared it to the most common method of the concrete plant delivering the product to the construction site. Vertical integration by the contractor could provide the contractor with a known delivery time and give more awareness of the location of the truck. The entire system, from the availability of the ingredients to the process of mixing within the plant, is examined for the potential to become a JIT delivery system and to use a pull system instead of a push.

In comparison to an LLC, concrete production and delivery is very similar relative to time. Concrete is a perishable product and expires after a certain time parameter upon production. The usability of the concrete expires at a certain known time after production and must be utilized prior to expiration. This is similar to tritium in that after it is produced it has a known life, but a life which is longer than ready mix concrete. The current method of production within the Savannah River Site tritium reservoir production plant is an elongated pull system. The system currently will not produce excess inventory and awaits the forecasted demand to be sent by the DoD.

History of Weapon Maintenance Policy

Nuclear Weapon Maintenance Policy is guided by the Air Force Instruction (AFI) 21-204, *Nuclear Weapons Maintenance*. This guidance provides procedures and guidelines that the Air Force, at varying levels, must follow. Throughout the years this policy has adapted to an ever-changing environment. Maintenance managers use AFI 21-204 to forecast weapon maintenance and the demand that will be placed on DOE to support LLC replacement. Current policy, published 17 December 2015, states that a unit will develop and submit their LLC support forecast schedule no later than 1 February for the next Fiscal Year. As LLCs are forced shipped to the unit, the unit may accomplish the LLCE at any time after LLC support arrives (Air Force/A4LW, 2015). This policy is a complete reversal of how the policy was written in AFI 21-204 published 16 September 2003. In 2003, the policy stated that the LLCs would arrive approximately 2-months prior to weapon due date (HQ USAF/ILMW, 2003). The unit was allowed to request earlier delivery of the LLC to higher headquarters but the request could only be based on a one-time requirement such as de-conflicting maintenance schedules, coinciding with an inspection, or for ongoing annual projections to optimize unit maintenance scheduling and workload leveling. A review of *AFI 21-204* policy between 2003 and 2015 in Table 1 shows the trend of a more relaxed LLC support schedule, allowing maintenance managers to adjust LLC support and maintenance actions as needed or desired.

The current policy allows maintenance managers to adjust their schedule according to one-time requirements, inspections, de-conflict maintenance schedules, ongoing annual schedules, and leveling the workload while ensuring the replacement of the LLC prior to expiration (HQ USAF/ILMW, 2003). For example, a rotary launcher within a B-52 *Stratofortress* can hold 8 Air Launched Cruise Missiles (ALCM). The goal of a maintenance

Table 1: AFI 21-204 Historical Guidance

Publication Year	Shipped	Restriction
2003	Approximately 2 Months prior to Due Date	LLCE must be completed within 6 Months of due date
2005	Approximately 2 Months prior to Due Date	LLCE must be completed within 6 Months of due date
2007	Will be delivered in time to allow maintenance actions to be accomplished prior to due date	LLCE must be completed within 6 Months of due date
2008	Will be delivered in time to allow maintenance actions to be accomplished prior to due date	LLCE must be completed within 6 Months of due date
2009	Will be delivered in time to allow maintenance actions to be accomplished prior to due date	LLCE must be completed within 6 Months of due date; Complete within 60 days of LLC receipt
2015	Units develop forecasted need and delivery will be based on forecast with time to allow for maintenance actions	None

manager is to align all 8 of the ALCMs so that all their recurring maintenance actions can occur within the same time-period (Deputy Assistant Secretary of Defense Nuclear Matters, 2016). If all 8 LLCEs are conducted at the same time, the handling operations of that rotary are limited. The problem encountered when aligning all 8 weapons to expire within the same month occurs when a single defect is found during inspection of the rotary. If a defect is found, a different ALCM could be assigned to the rotary which will have a different maintenance cycle causing further workload adjustments.

Current policy allows maintenance managers to determine when support is needed for the replacement of the weapons within their purview. Figure 3 shows a blank forecast example provided by AFI 21-204 for maintenance managers to produce the LLC support schedule for their unit (Secretary of the Air Force, 2015). No incentive is made for maintenance managers to consider LLC utilization when forecasting the maintenance. Instead, maintenance managers are incentivized to perform the maintenance early in order to minimize the risk of the maintenance not being completed on time. Another problem with the current policy, shown in the examination of the data later, is the large variance in the scheduling of maintenance actions. This occurs from the different methods that different maintenance managers use when creating their own schedule for replacement instead of being held to a restricted timeframe.

Delivery Month	Quantity	Weapon S/Ns	Remarks
October			
November			
December			
January			
February			
March			
April			
May			
June			
July			
August			
September			

Figure 3: Blank Template LLC Support Schedule

The example provided in Figure 3 is currently due from the units to higher headquarters on 1 February prior to the Fiscal Year of planning. This allows Air Force and DOE planners the time needed to properly forecast support for the production and transportation of LLCs to the unit. Current policy also allows maintenance managers the ability to change their forecasted long-range schedule date. This change is requested from the units no later than 90 days prior to the month of delivery (Secretary of the Air Force, 2015).

Limited Life Components

LLC production has only become more difficult and costly for the Department of Energy (DOE Office of Audit Services, 2003). Tritium, within the stockpile, is a perishable entity that has a known rate of decay of a half-life of 12.3 years. The design of a nuclear weapon requires tritium reservoirs to be exchanged at a known interval (U.S. General Accounting Office, 1997).

These intervals vary depending on the weapon system in question and will not be shown throughout this research. This research will use a range of life cycles from 1 to 5 years that will be assumed for the entire stockpile, this range of years is generated from the 2016 Nuclear Matters Handbook which states “These weapons undergo regular replacement of LLCs, usually at intervals of a few years” (Deputy Assistant Secretary of Defense Nuclear Matters, 2016). These maintenance actions ensure that the weapon and associated components will perform to the design specifications of the system if employed.

Currently, Savannah River Site is prepared to meet tritium demands by first recycling tritium from the stockpile as much as possible and in the production of tritium through the Tennessee Valley Authority (Office of Chief Financial Officer, 2016). The recycling of tritium is done by taking the tritium reservoirs that have been removed from active weapons and retrieving as much of the tritium as possible from the reservoir. This method has enabled the tritium stockpile to be replenished and not need as much production (Savannah River Nuclear Solutions, 2013). The current inventory of tritium has allowed the production of new tritium to remain low. However, to meet future demand, production rates of tritium must increase (Department of Energy, 2015). The current method that has been in place since 2003 to produce tritium is through the irradiation of tritium-producing burnable absorber rods (TPBARs). TPBARs are irradiated within the reactor located at the Tennessee Valley Authority (D'Agostino, 2011). Once irradiated, the bars are transferred to the Savannah River Site extraction facility where the tritium is captured and the TPBARs are then disposed of as low-level radioactive waste (Department of Energy, 2015). The captured tritium gas is piped to the Savannah River Site Tritium Loading and Unloading Facility where the tritium is stored in the national tritium stockpile, purified, and loaded into limited-life tritium reservoirs (Savannah River Nuclear

Solutions, 2013). The major factors that are incorporated into the demand of tritium stem from weapon LLCE, tritium required for LEPs, and the production efficiency of the TPBARs (Department of Energy, 2015). In order to meet the tritium demand from the 2010 Nuclear Posture Review, the demand in FY14 was 704 TPBARs and is projected to increase to 2,704 TPABARs by FY23. This increase in demand for TPBARs causes the demand for unobligated low-enriched uranium. NNSA uses the unobligated low-enriched uranium for national defense purposes but currently there is no supply of the uranium because of the shutdown of the Paducah Gaseous Diffusion Plant in 2013 (Department of Energy, 2017). While plans are underway within DOE to try and find alternative methods of supplying low-enriched uranium, this demonstrates that the current price for tritium of $100,000 to $200,000 can only be expected to increase, emphasizing the value of tritium within the national security complex (Willms, 2003).

The current process for replacement of the LLCs results in a Prisoner's Dilemma between the DOE and DoD. A Prisoner's Dilemma is when two players have two options in which the outcomes are based on the simultaneous choices of each respective player. This dilemma is illustrated by the example of two prisoners being questioned by the police in which their respective sentence will be reduced if that prisoner talks to the police, but if both prisoners talk then their sentences will both be vastly longer (Cachon & Netessine, 2003). The DoD is incentivized to exchange the components early to minimize the risk of the weapon going overdue prior to LLCE and therefore being considered non-operational. The DOE is likewise incentivized to use up the entire life of the component because of the high cost of the tritium within a tritium reservoir. Within Game Theory, this results in the Prisoner's Dilemma along the supply chain as represented in Table 2 (Cachon & Netessine, 2003). Both the DOE and the DoD have two options when it comes to LLCs. DOE can cooperate with the DoD and produce them according to the long-range schedule, resulting in a lower utilization rate, or the DOE can produce the tritium reservoirs according to the expiration of the components, resulting in a higher utilization rate and a lower cost. The DoD has similar options in regards to scheduling the components for replacement. They can cooperate and schedule the components close to the due date, increasing the risk of not exchanging the components prior to due date, or the DoD can schedule maintenance actions early to reduce the risk. Currently, the DoD is not incentivized to cooperate because the funds that ultimately pay for the tritium production and supply comes from the DOE and the DOE is not incentivized to schedule the components early because the risk is placed on the DoD. The ultimate consumer, the tax payer, has a buy in for both systems to work together to reach the goal of a medium risk for the weapon and a medium utilization rate.

Table 2: DoD vs DOE Prisoner's Dilemma

		DOE	
	DOE, DOD	Cooperate	Cheat
DoD	Cooperate	Med Utilization, Med Risk	High Utilization, High Risk
	Cheat	Low Utilization, Low Risk	Low Utilization, High Risk

This research seeks to quantify the fundamental trade off experienced between the risk associated with scheduling the maintenance actions at different time intervals compared to the utilization of the component's life cycle which is the cost variable.

III. Methodology

Overview

This research uses current policy to produce a simulation model which compares the current system against potential policy changes to try and find a method that satisfies the DoD and DOE desires of on time maintenance and component utilization. Keloton, Sadowski and Zupick developed a generic outline to follow when building a simulation in their book *Simulation with Arena* (Kelton, Sadowski, & Zupick, 2009). The steps in the outline are:

1. Formulate the problem
2. Design a solution methodology
3. Specify the system and subsystems
4. Construct a model
5. Verify and Validate the model
6. Design and conduct experiments
7. Present and preserve the results

The Methodology chapter of this research covers steps one through five while the Analysis and Results chapter will cover steps six and seven.

Formulate the Problem

The problem in this research is to define and measure the success of the current system of forecasting and performing maintenance actions on nuclear weapons. Success in this research is defined as minimizing the risk, where risk is defined as the number of times maintenance is performed after the due date of the component, and to maximize the utilization of the component. Current policy in the Air Force allows maintenance managers to forecast maintenance actions and demand of LLCs based on their own objectives outlines in Air Force Policy (Secretary of the Air Force, 2015). If the Air Force accomplishes the maintenance actions further from the due date, the cost to the tax payer will increase because the amount of resources needed increases. This research then tries to measure different policies that would result in varying rates of risk and utilization.

Design a Solution

The solution to the problem was developed by observing the current design of the system using Air Force Instructions. The desired solution is to replicate the current methods used in the system to find the risk and utilization and then to change specific parameters within the simulation to try and find a method that will better suit a cooperative solution for both the DOE and DoD. The simulation is built using ARENA 14.0, designed by Rockwell, because of the ease of use when replicating the process.

Specify the System

The system was replicated using AFI 21-204 and the description of the methods by Air Force unit personnel to outline certain requirements of the unit and to outline the timeline that occurs when forecasting an LLCE (Secretary of the Air Force, 2015). Figure 4 shows the current system and a brief description of each step in the process. The measure of performance (MOP) used for measuring utilization are:

- Difference between the time of LLC production and installation
- Difference between the time the LLC is uninstalled and the due date of the LLC

The MOPs measuring the risk of not exchanging the LLC prior to due date are:

- The number of times maintenance is performed past due date divided by the total number of weapons maintained

The system is divided into two parts, the Air Force side which focuses on scheduling and accomplishing the maintenance actions on time, and the DOE side which focuses on producing and delivering the LLC according to the long-range forecast. The forecast is determined from the current policy and is created by the Air Force.

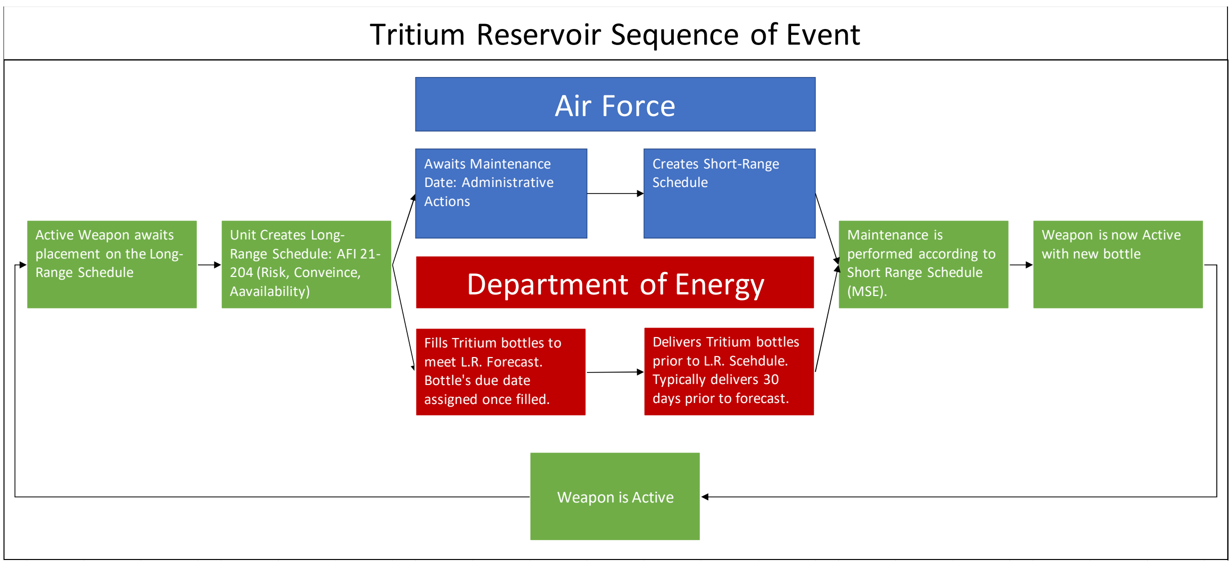


Figure 4: Tritium Reservoir Sequence of Events

While Figure 4 looks at the entire system, further analysis was desired on a single component itself to show the life of a single tritium bottle. Using Figure 5, once a bottle is produced by DOE/Savannah River Site its expiration date is set. Anytime in-between the bottle being produced and the bottle not being installed in a weapon is unutilized time. Anytime that a bottle is removed prior to the expiration date is also unutilized time. The system must be able to record the two times to be able to determine the final utilization rate of the tritium bottle.

Conversely, every circumstance that a tritium bottle is not replaced prior to its expiration date is a failure of the system. This measured by using a percentage of number failed over total number maintained. The model must be able to determine whether the maintenance actions were performed prior to the due date.

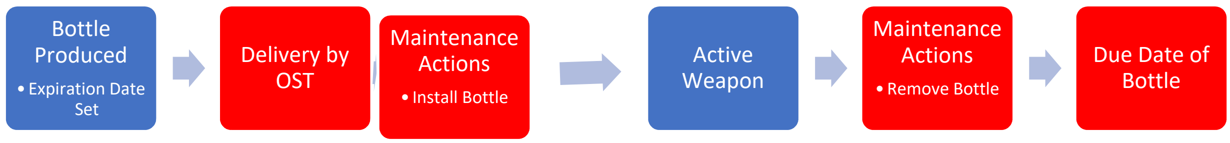


Figure 5: Tritium Reservoir Life Cycle

Construct a Model

Utilizing Figure 4, the researcher created the model in ARENA 14.0 to replicate the system. The model represents each step in the process of creating a long-range schedule, production of an LLC based on the long-range schedule, delivery of the LLC based on the long-range schedule, and the maintenance effectiveness of executing according to the long-range schedule. Long-range schedules, due dates, and dates of the maintenance actions were recorded from two different maintenance units (any sensitive information was removed prior to examination by the researcher). The data were populated into two different data sets.

The first data set is used to examine the difference between the due date of the LLC and the date that was scheduled on the long-range schedule. This data set is used to replicate the current process of LLCE scheduling and to set the LLC production dates. These data represent the number of days early that the maintenance actions were scheduled on the long-range schedule, shown in the histogram in Figure 6. These data are used to create the long-range schedule which DOE uses to schedule the production and delivery of LLCs to the unit.

For these data, the limitation is the lack of information from multiple sources. These data are used as a validation method of the model in order to show that the model is accurately predicting the current system. These data are based on the current Air Force policy of allowing maintenance managers at the unit to forecast the dates of maintenance actions and allows the maintenance manager to cause a large variance in scheduling procedures. These data was then modeled using Input Analyzer, a function within ARENA 14.0, to find the best fit distribution of the data.

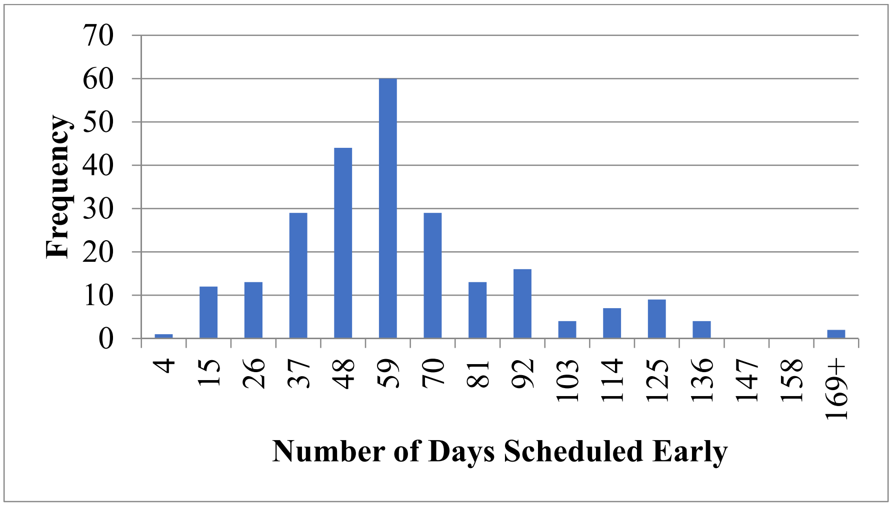


Figure 6: Due vs Scheduled

Utilizing Input Analyzer from ARENA 14.0, the best fit distribution is found to be a Weibull distribution seen in Figure 7. In testing the Weibull distribution, the Chi Square Test results in a failure and a rejection of the null hypothesis that the distribution fits the data, this could be the result of having a large sample size of 255 observations. Although the test rejects the null hypothesis of fitting a Weibull distribution, the researcher decided that the Weibull distribution was the best fit because of the characteristics of the distribution. The Weibull distribution is bounded on the left by zero which aligns with the fact that a rational maintenance manager would not schedule the maintenance actions on the long-range schedule after the due date of the LLC. Another characteristic that is desired is the right-hand tail of the Weibull distribution. The largest value found from observation of the data was 169 days prior to LLC due date but, according to Air Force Instruction, this is not the maximum number of days early the maintenance actions could be scheduled. According to current Air Force Instruction the actions could be scheduled earlier but the likelihood of an early schedule date in comparison to the due date approaches zero if the maintenance manager is planning rationally. The final characteristic that is desired of the Weibull distribution is the high peak, while the observed data has a higher peak than is represented in the Weibull distribution, the accuracy of the distribution increases quickly as seen in Table 3.

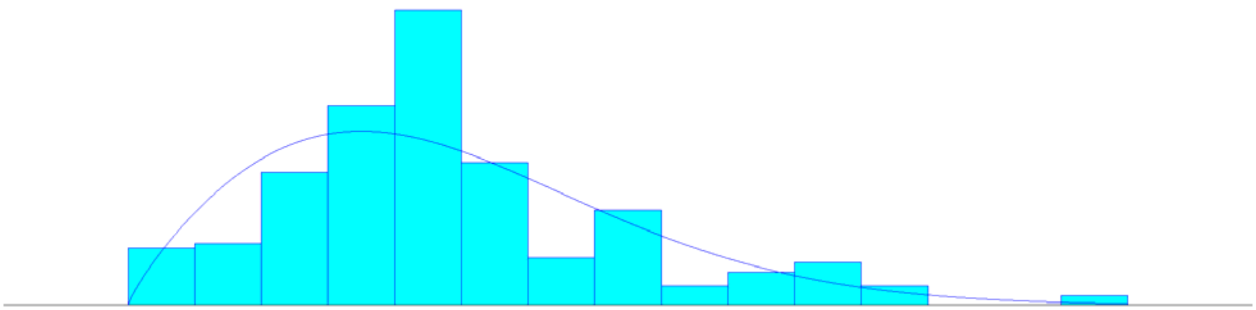


Figure 7: Due vs Scheduled Distribution

Table 3: Accuracy of Weibull Distribution

Days	Observed	Weibull	Difference
26	10.70%	14.20%	-3.50%
48	40.74%	41.93%	-1.19%
70	77.37%	69.43%	7.94%
92	89.30%	87.56%	1.74%
114	93.83%	96.11%	-2.28%
125	97.53%	98.03%	-0.50%

The second data set examines the difference between the long range schedule date and the date of execution of the maintenance actions. This data set is used to show how effective the Air Force unit is at executing the long-range schedule and will be called the *long-range maintenance effectiveness*. Histograms were created for both Base 1's and Base 2's long-range scheduling effectiveness is shown in Figure 8 and Figure 9 respectively. From observation of the histograms, the researcher decided that the best fit distribution is a Laplace distribution. The researcher chose this distribution because of the extremely high peak centered on the median of both data sets. The Laplace distribution represents two exponential distributions back to back and allows negative values which is why the exponential distribution could not be used.

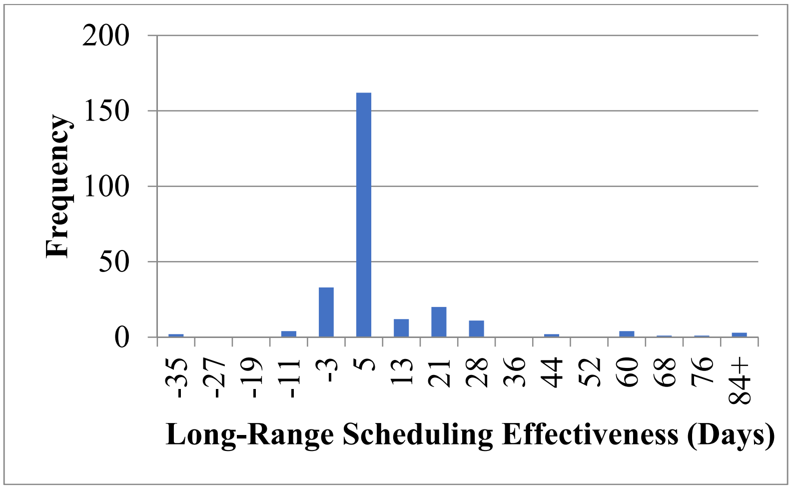


Figure 8: Base 1 Maintenance Scheduling Effectiveness

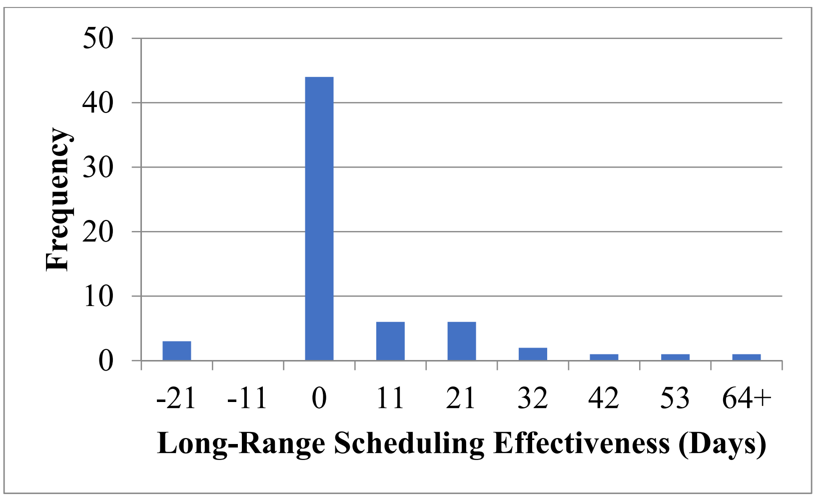


Figure 9: Base 2 Long-Range Scheduling Effectiveness

The Laplace distribution uses a parameter estimation, **Error! Reference source not found.**, which finds the parameter which will best fit the data.

$$\hat{b} = \frac{1}{N}\sum_{i-1}^{N}|x_i - \hat{\mu}| \quad (1)$$

Where $\hat{b}$ is the parameter estimate

i=1 to n is the index number of the value within the N observations

x_i is the value within the data set on the i^{th} observation

$\hat{\mu}$ is the median value within the data set

Using the Laplace parameter estimation method from the book *The Laplace Distribution and Generalizations* by Kotz, Kozubowski, and Podgorski, the researcher found that the parameter estimator for Base 1 and Base 2, seen in Table 4, only vary slightly but both parameters were used in the validation method of the model which is discussed in the Verify and Validate the Model section to follow (Kotz, Kozubowski, & Pogorski, 2001).

Table 4: Laplace Parameter Estimation

Parameter Estimation		
	Base 1	Base 2
N	255	64
μ hat	0	0
b hat	7.0235	7.25

The result from the parameter estimators produces the ability to determine the Laplace distribution for each Base. These Laplace distributions are compared to the histograms of Base 1 and Base 2 in Figure 10 and Figure 11 respectively.

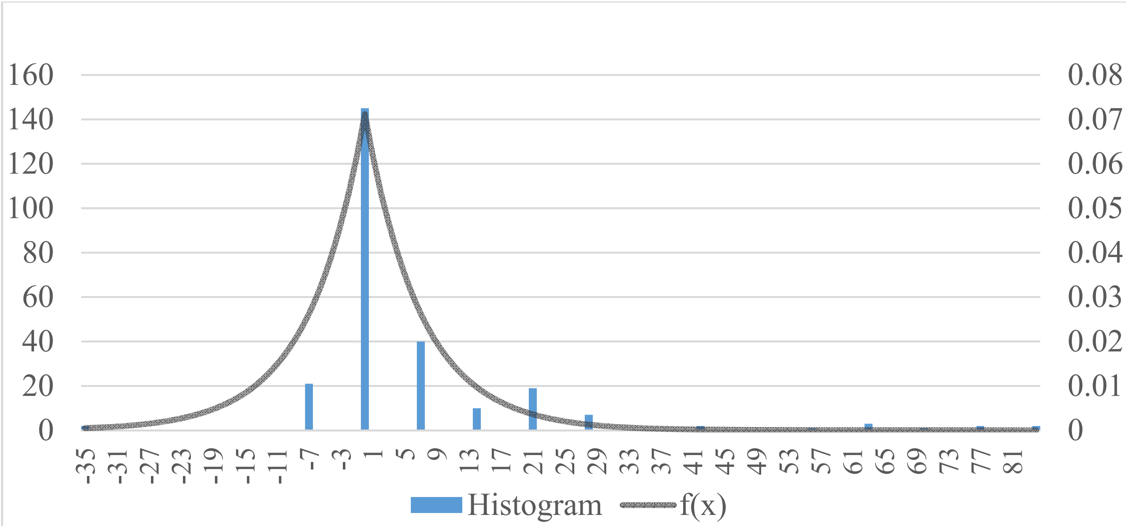


Figure 10: Base 1 Laplace

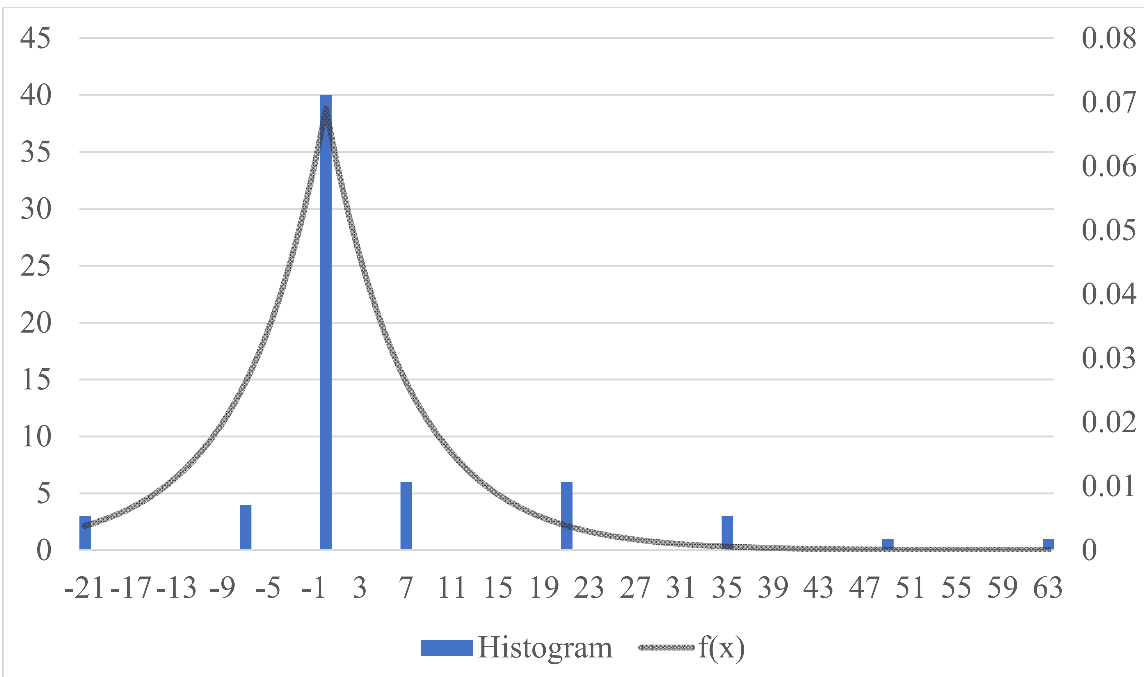


Figure 11: Base 2 Laplace

The researcher decided that since the distributions are so similar (see Figure 12 and Figure 13 for comparison and difference between the data respectively), that the results from

Base 1 would be used because of the completeness of the data observed from Base 1 with the inclusion of the due date of the components. The assumption is made throughout the experiments that the effectiveness of the unit to complete maintenance according to the scheduled date on the long-range will not change.

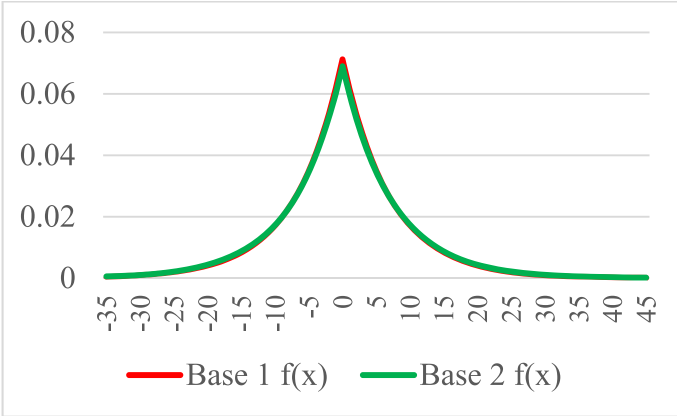


Figure 12: Laplace Distribution Comparison: Base 1 vs Base 2

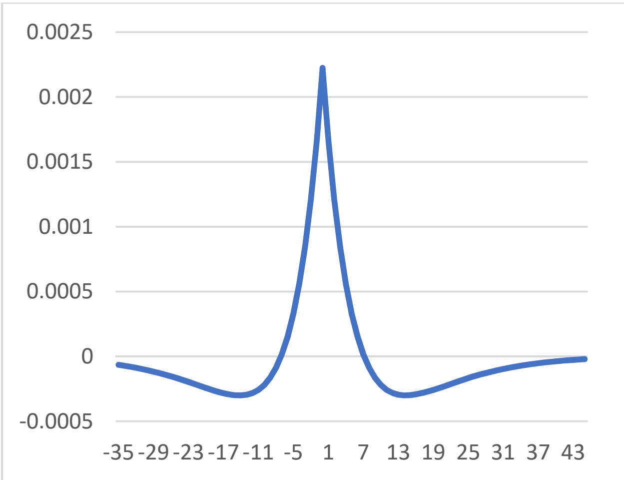


Figure 13: Laplace Distribution Difference

The researcher then ensured that no other sources of variance could be found within the current system and found that one source of variability was left within the system, the delivery of the components by DOE/OST. The researcher then sought clarification from subject matter experts to find if data were available to find the distribution and accuracy of delivery. Data were not available, but the subject matter experts provided minimum, most likely, and maximum quantities of 15, 30, and 60 days respectively (Lueck, 2016). The researcher decided to use a Triangular distribution to set the delivery time proceeding the production of the LLC. The researcher also used an adjustable decision variable to determine if the delivery was achieved or not. Subject matter experts explained that if a delivery was delayed, typically it would be delayed by at most seven days. The researcher decided to use this information to further test the sensitivity of the model which is discussed in the next section.

The next step was for the researcher to determine the simulation's time interval. The actual timelines for the life span of an LLC are classified and the time period is not significant for the model. Instead, the model investigates the number of maintenance cycles a weapon will experience over a fixed time horizon. The researcher decided that five life cycles will provide enough information to determine the validity of the model and that the number of entities that will enter the system will be the total number of weapons obligated by the New START treaty, 1,550 weapons. This will provide the data needed to show the varying levels of risk and utilization per cycle and can then be applied to certain time parameters that will be assumed and examined later in the research.

The final step was to determine the number of replications needed in order to find a confidence interval of 95%. The current design of the system has no queuing within the model which creates a simulation with entities that have independence from one another. The independence of the entities enables each entity's experience to be a single replication. The single replication of the model per entity results in a total number of 1,550 replications.

Verify and Validate the Model

Verification of the model was conducted by the researcher within ARENA 14.0 by using the step by step animation tool. This was conducted with only one entity in the system up to the full entity compliment of 1,550 at varying intervals. The animation process in ARENA showed that the model was running as desired. Different parameters within the model were changed to see if the model would respond as necessary and the model ran as predicted.

The first validation method used was to run the model and compare to the observed data. The first comparison was to compare the values assigned by the distributions with the actual data. Figure 14 shows the comparison of the observed data from Base 1 and the Weibull distribution which represents the number of days early the unit will schedule the weapon for an LLCE operation prior to due date.

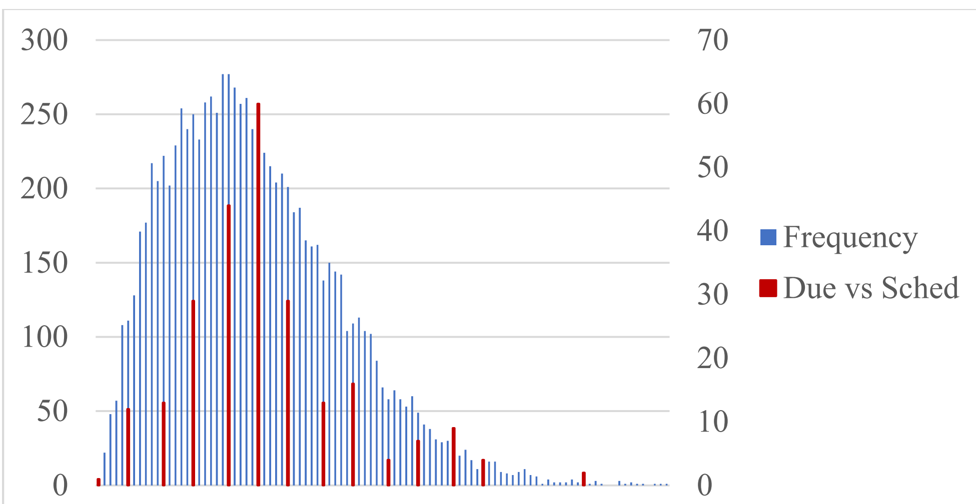


Figure 14: Base 1 Observed vs Weibull

The next validation conducted examined the long-range scheduling effectiveness and compared the observed data from the model and the actual data from Base 1 and Base 2, seen in Figure 15 and Figure 16 respectively.

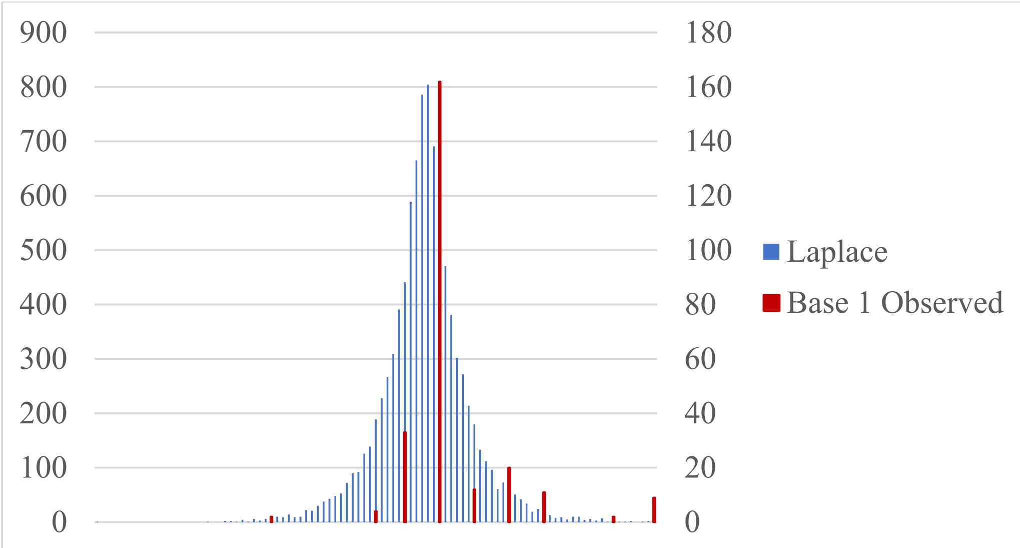


Figure 15: Base 1 Observed vs Laplace

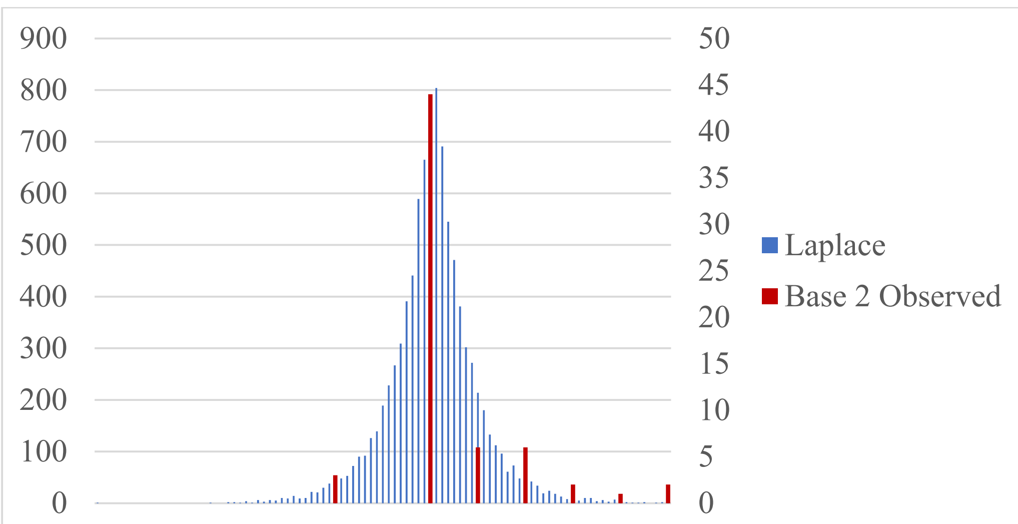


Figure 16: Base 2 Observed vs Laplace

While all three of the distributions are not perfect, it can be seen that the error observed favors the unit's effectiveness to execute the maintenance according to the long-range schedule. This means that the model will more often show the unit as scheduling the maintenance action closer to the due date as well as effectively executing the long-range date more often. The error that is caused in this will result in a higher utilization than what may actually be occurring in the field. The researcher decided that this error is acceptable because it favors the unit's utilization compared to the minimization of risk.

The next validation completed by the researcher was the comparison of Base 1 to Base 2 found in Table 5 with the different Laplace distributions assigned to each Base. The assumption was made that Base 2 would have nearly identical data and that the Weibull distribution would still be a best fit distribution when examining Base 2. This assumption resulted in the product of the comparison to truly be examining the difference in the Laplace parameter estimation and the effect they will have on the model. The comparison of Base 1 and Base 2 shows little difference between the two Laplace parameter estimations. The researcher decided because the difference was so small, the complete data of Base 1 would be used in the experiments.

Table 5: Base Comparison

Base Comparison			
	Base 1	Base 2	Difference
Avg Days	92.13	92.01	0.12
St Dev	31.12	31.18	-0.06
% Late	0.82%	0.86%	-0.04%
# Late	76.50	80.50	-4.00
# On Time	9303.50	9303.00	0.50
Total	9380.00	9383.50	-3.50

The final validation step conducted by the researcher is to compare the actual results observed from the unit in comparison with the model seen in Table 6. The comparison shows that each area of measurement within the model represents the actual data with minimal difference or with a slight difference that will ultimately skew the results in the favor of a higher utilization and lower risk. This is because the model will, on average, show that the unit schedules the maintenance actions closer to the due date while also executing the maintenance actions closer to the long-range schedule date. This will result in the model portraying the unit as replacing the LLC's at a closer date to the due date more efficiently resulting in a higher utilization rate with nearly the same percent of weapons being completed past the due date as the actual observed data.

Table 6: Model vs Observed

Model vs Actual			
	Model	Base 1 Observed	Difference
Average Days Early	53.43	56.53	3.10
Standard Deviation	30.27	29.53	-0.74
Average Percent Late	0.8155%	0.8163%	0.0008%
Standard Deviation	0.025%		
Completion vs Scheduled	-0.05	4.09	4.14
Standard Deviation	9.89	15.10	5.21
Due vs Scheduled	57.17	57.10	-0.07
Standard Deviation	30.01	28.97	-1.04

IV. Analysis and Results

Design and Conduct Experiments

The experiments were designed around the principal objective of the research which is to determine if there exists a policy that satisfies both DOE and DoD in their desired objectives. The experiments were therefore designed to examine the rate of utilization of the LLC, the number of wasted days, and the number of weapon maintenance actions that occurred past the due date of the weapon. Throughout the experiments the assumption was made to use an exchange time period of 365 days as a base case but later the examination is made into what the utilization rate and risk percentage would be if the life span of the LLC varied from one year to five years days at intervals of one year. The different experiments conducted to compare with the current system are:

- Alter the Long Range Schedule Policy
- Alter the Delivery Accuracy
- Alter the Deliver Time
- Implement a Rational Long Range Scheduling Policy

Present and Preserve the Results

Long Range Schedule Policy

The first designed experiment is to alter the time to which a unit could schedule the maintenance actions on the long range schedule. The researcher first picked 60 days prior to LLC expiration as a starting point because current procedures result in an average of 57.09 days and the comparison wanted to be looked at to see if the variance in scheduling procedures resulted in the low utilization. The researcher chose to use intervals of five days and to then fine tune the amount of days to be able to show the different capabilities of the unit if policy dictated an exact timeframe on when to schedule the maintenance action. The results from this experiment, presented in Figure 17, show that the difference between scheduling the maintenance actions at 60 days prior to due date compared to 30 days results in a higher utilization of the LLC. Conversely, the risk percentage between the 60 and 30 day policies increases. The significant determination in this comparison though is when compared to the current system, a policy of constantly scheduling the maintenance actions 60 days prior to due date will attain a percentage of overdue weapons as nearly zero while also obtaining the same utilization, shown as the number of days unused of the LLC. The change in policy from the current system to a 30 day policy would result in nearly a month savings in the utilization while also achieving a reduction in percentage of failure to complete the maintenance compared with the current system. The percentage of failure to complete the maintenance can be attributed to the current system having an average of 57.09 days with a standard deviation of 30.27 days. This experiment also resulted in finding that as the policy of long range scheduling approaches zero, the risk of not performing the maintenance on time increases to beyond that of the current system and this risk may not be acceptable to the DoD nor will it incentivize DoD units to adopt such a policy. This experiment resulted in the researcher using the 30 day policy as a comparison point for the later experiments.

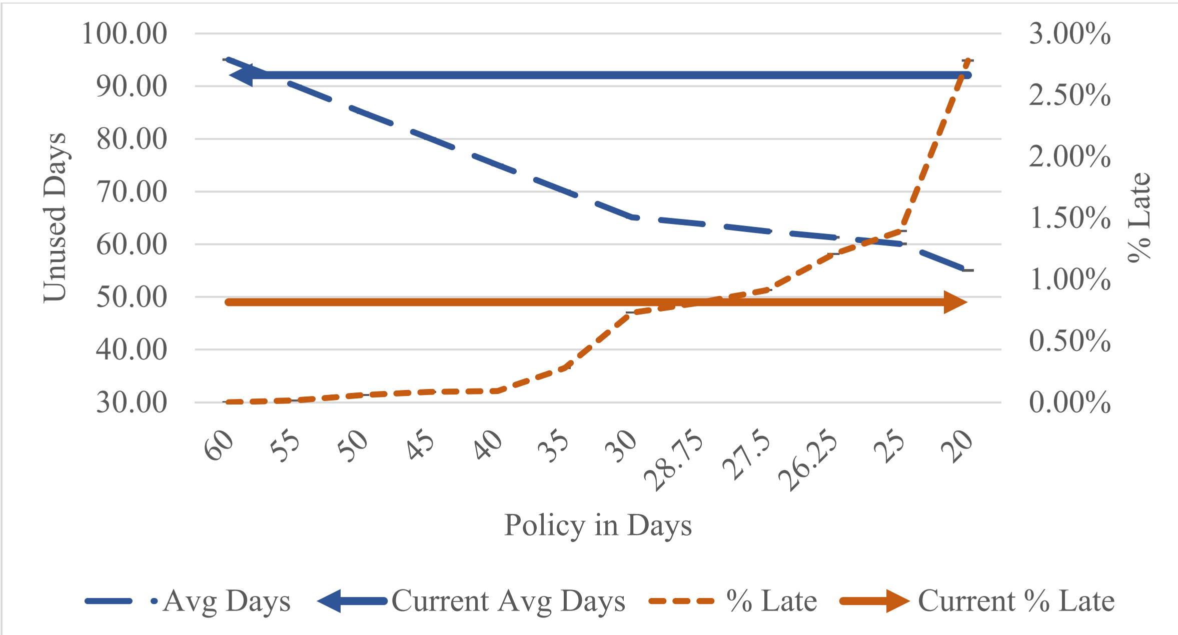


Figure 17: Alter Long Range Schedule Policy

<u>Delivery Accuracy</u>

The next experiment that was conducted was to alter the accuracy of the delivery. This could be caused by weather or an aircraft breakdown prior to delivery and would result in the delivery being delayed 7 days. The delay is assumed to be a constant delay. This experiment is designed to determine the current system's and 30 day policy model's sensitivity to a delay in the delivery of an LLC. The results of the experiment shown in Figure 18 show that the model acts as predicted and that the percentage of weapons that are completed past the due date increase slightly and that the total number of unused days remain constant. The number of unused days remaining constant can be explained by the limited number of LLCs that are actually delayed would not have a significant impact on the average number of days unused for each LLC because delivery is scheduled with a buffer assigned by a Triangular distribution discussed previously with 15, 30, and 60 days being the respective minimum, most likely, and maximum values. This also shows that current policy could have significant impact if the supply chain of LLCs is interrupted by any significant delay. The 30 day policy would also be impacted by any significant impact in the supply chain but the risk would be maintained below what the current policy functions at even at 100% delivery accuracy.

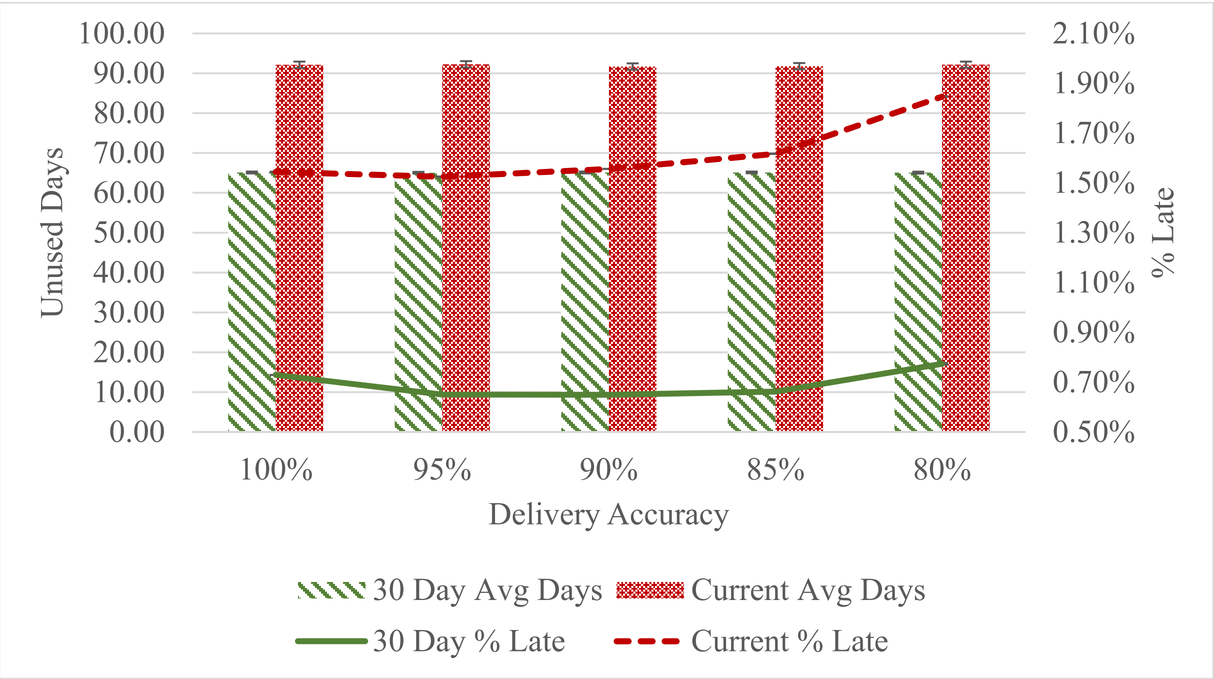


Figure 18: Delivery Accuracy

<u>Delivery Time</u>

The delivery time experiment was conducted to test the sensitivity of the current system and the 30 day policy system against the fluctuation of the delivery time frame. The current delivery time frame assumes a Triangular distribution with a minimum, most likely, and maximum of 15, 30, and 60 days respectively. The experiment changed the minimum and maximum values at intervals of 7.5 days for the minimum and 15 days for the maximum. The results of the experiment are shown in Figure 19. The results show that as the delivery time is fine-tuned and approach a constant value, the percent of weapons that are late increase. This experiment resulted in showing that the model is sensitive to changes in the delivery time, but in a manner that is counter intuitive. When only considering the 30 day policy, the percent of late weapons increases as the delivery date approaches the constant value of 30 days. This is because the 30 day policy sets a standard that the maintenance actions will be conducted 30 days prior to weapon due date and as the delivery approaches the 30 days prior to the scheduled date, the percent late would become a constant with no variance beyond that of the long-range maintenance scheduling effectiveness (the Laplace distribution). In comparison the current policy does show a trend in its sensitivity to the delivery time being adjusted. This could be the result of the variance being impacted by both the long-range maintenance scheduling effectiveness (Laplace distribution) and the long-range scheduling policy that is currently being conducted by Air Force units (the Weibull distribution) and further research would be needed to determine this finding. The results of this experiment show that with a constant policy of maintenance actions being scheduled 30 days prior to weapon due date, the sensitivity to the change in delivery will not significantly impact the percentage of weapons that go overdue prior to maintenance actions. This experiment also shows that as the delivery time becomes constant, the total number of unused days remaining on the LLC decrease.

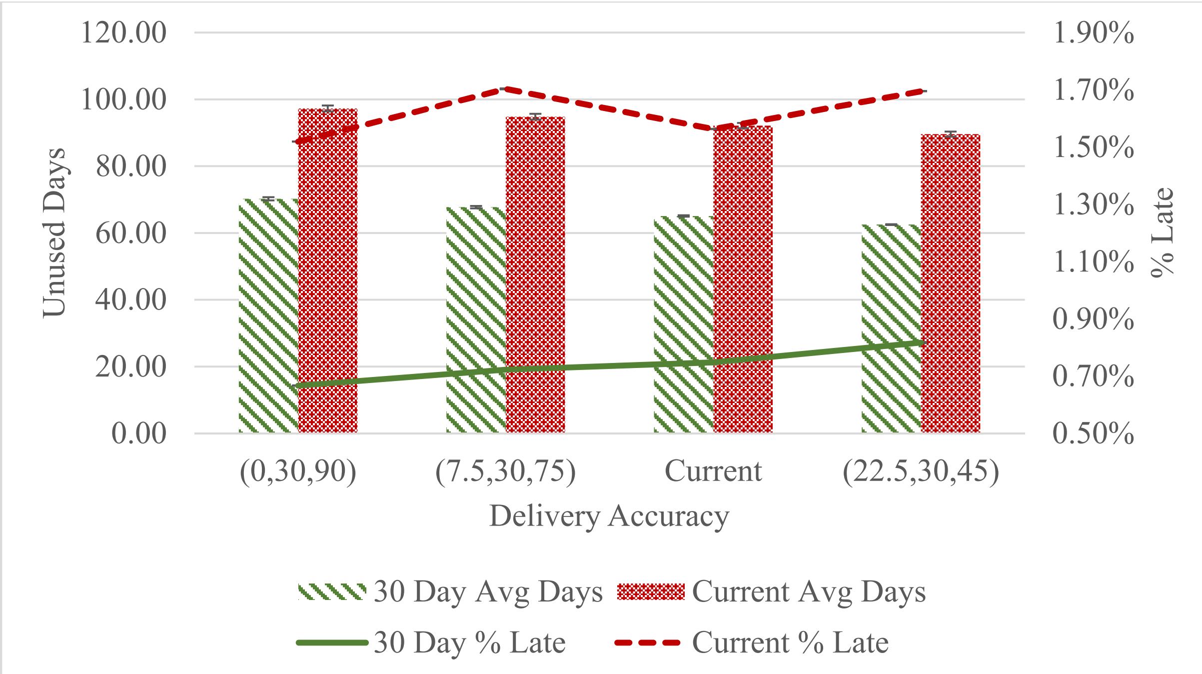


Figure 19: Delivery Time

<u>Potential Policy</u>

The final experiment was designed to try and find a maintenance policy that is rational to both reduce the number of unused days and reduce the risk to the Air Force of conducting maintenance operations past the due date of an LLC. The researcher decided to try two different distributions because no data were available to show how a unit would respond to such a change in policy. The variable that is changed is the long-range schedule date in comparison to the due date. This variable is changed into two different distributions that potentially could represent the actual data if such a policy change was made. The two different distributions that are used are the Triangular and Uniform distributions. The researcher tried to set time frames that would be rational to Air Force units and allow Air Force units to adjust their long-range schedule in order to line-up other maintenance actions, personnel availability, load leveling, and any reason the maintenance unit could decide that the scheduled date of maintenance action should be changed within a reasonable timeframe and in accordance with the policy.

The two different distributions were assigned different time periods to allow the decision to be made of what would be the best fit for maintenance organizations. The potential policy changes are compared to the current system as well as the 30 day policy. The three different policy changes that were tested are:

- Unit must schedule the LLCE between 30 and 60 days from LLC due date
- Unit must schedule the LLCE between 30 and 51 days from LLC due date
- Unit must schedule the LLCE between 23 and 51 days from LLC due date

The results of this experiment in Figure 20 show that changing the policy to a restriction of 30 to 60 days will result in the most drastic reduction in the percent of maintenance actions that are completed after the due date while also potentially reducing the number of unused days remaining in an LLC. Figure 20 compares the current policy and the 30 day strict policy to that of the potential policies. The comparison is made for each policy with the respective distribution that is assumed the maintenance unit will follow, either a Uniform or Triangular Distribution.

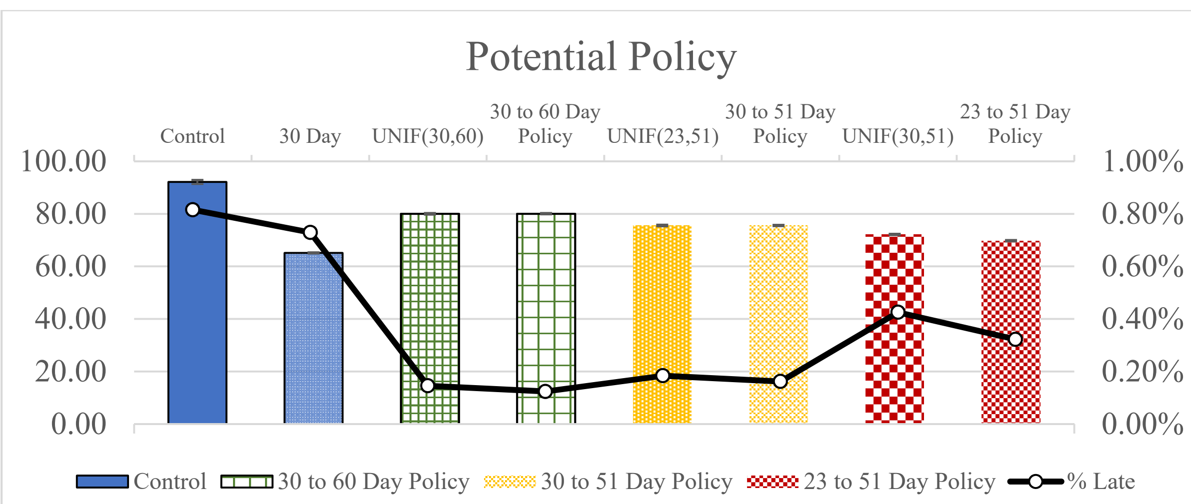


Figure 20: Potential Policy Comparison

Comparison of Potential Policies

Using the results from the comparison of potential policies, the next comparison examined the potential cost savings from adjusting the policy. This calculation was formulated by taking the average number of components used throughout the replication of the model. These costs would include the cost of replacing all 1,550 weapons authorized in accordance with New START and the assumption that the cost of one LLC was only the low estimate for the cost of a single gram of tritium. The assumption was made for this calculation that each LLC only costs $100,000. This is made because the true cost for an LLC is unknown but the lower threshold for a single gram of tritium is used to show the potential cost if the assumption is made that each LLC required one gram. The results of this cost calculation are then divided by the assumed replacement time frame. Since the actual time frame of specific LLC's within specific weapon systems is classified, the researcher decided to apply a simple range from one to five years for replacement life cycle of the entire stockpile at an interval of one year. These data result in the assumed cost if the entire stockpile's LLCs had to be exchanged at the specific time parameter. The results in Figure 21 show that the cost associated with exchanging the LLCs is reduced by the factor of the time parameter in comparison to the single year replacement. In order to justify the policy the average of each model with the different Triangular and Uniform distributions was taken. This was done to allow for variance in scheduling practices accomplished by maintenance units while following the specified policy.

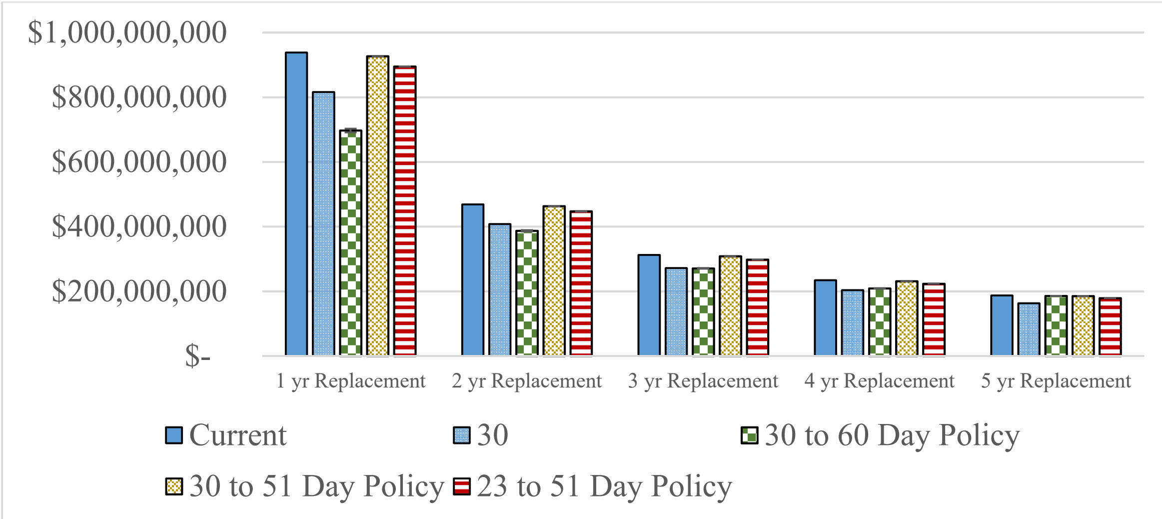


Figure 21: Cost of Replacement

While the cost associated with the change in policy is something of great interest to the DOE, the DoD would not be incentivized to change the policy because of the associated risk. While Figure 20 shows the reduction in risk according to the specified distribution selected according to the change in policy, the researcher decided a single value would be beneficial to try and minimize both the cost and the risk. The Prisoner's Dilemma exists between the two organizations when only looking at the interests of each organization but an observer takes a step back to find who the ultimate consumer is an alignment of interest begins to present itself. The ultimate consumer in this scenario is National Security and the society within the United States. This research assumes that society as a whole desires the risk of completing maintenance actions past due date to be minimized at the lowest possible cost to the DOE. This assumption is made because society has a cost associated with weapons not being on an operational status because of a failure to complete maintenance. Society also has a cost associated with the expenditure of valuable resources.

The following calculation was used to find the cost to society, assuming risk and cost are equally important:

$$\underset{\forall i}{\text{minimize}}\ m_i \ \ where\ \ m_i = K_i * E_i \tag{2}$$

where: m_i is the cost to society for implementing policy i from among n choices.

K_i is the average cost in dollars of the i^{th} policy.

E_i is the average risk of the i^{th} policy, expressed as a number bounded by [0, 1].

The objective of Equation 2 is to find the lowest cost-risk policy. The result is the optimal policy that would allow maintenance managers the needed flexibility to schedule maintenance actions according to their own needs while also minimizing tritium bottle replacement cost and risk. Figure 22 shows the m calculation for five candidate policies assuming 5 different replacement cycles. This shows that the optimal policy schedules the maintenance on the long range from 30 to 60 days prior to due date.

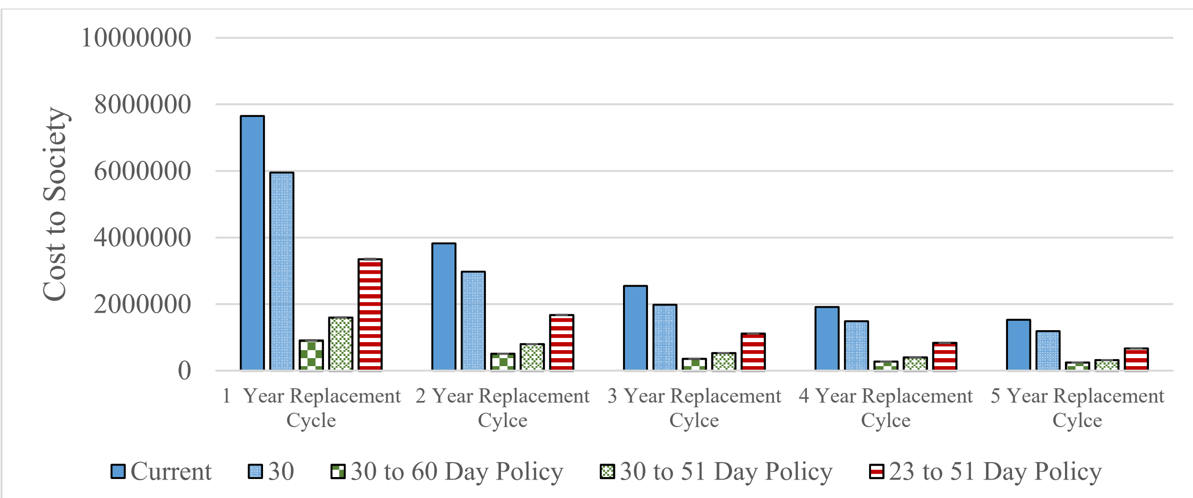


Figure 22: m Calculation

V. Conclusion and Recommendation

Recommendations for Action

Further analysis into the maintenance policy and practice should be conducted to better understand whether current policy should be sustained. This research looked at information from two locations but only received complete data from one location, this is a limitation in the research and further action could be conducted to validate the trend throughout all units. An examination of the effects from previous policy may also influence the rationale for the current policy. In 2003, the two month policy was in place and researching LLCEs during this time period may offer further explanation into the secondary effects of the policy.

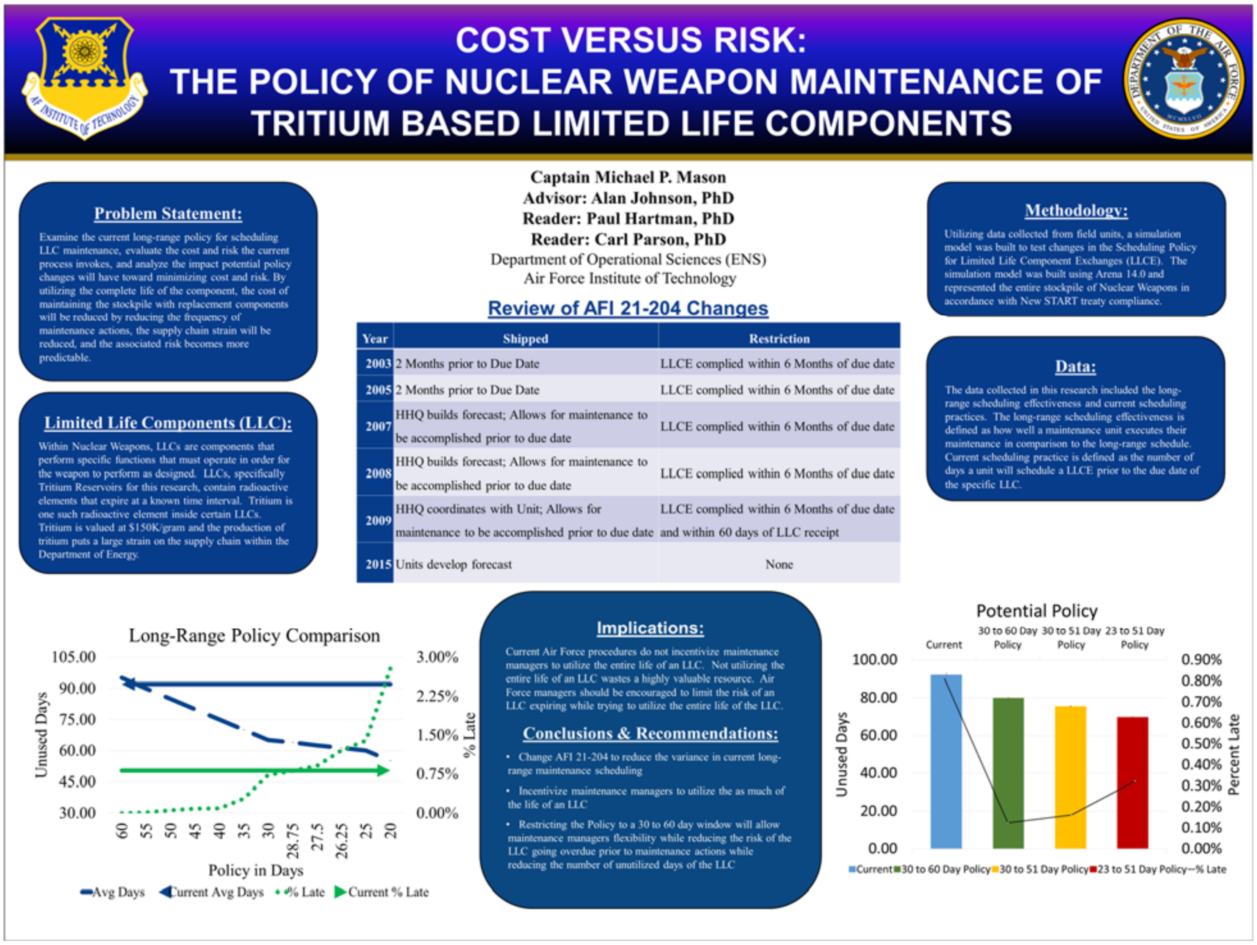
The adjustment of policy may not be beneficial to the DOE if they cannot readily adjust the production schedule to match the forecast. This research assumed that DOE has an immediate production capability to perfectly match the demand placed on the system. Further analysis into the DOE's production capabilities will show the true potential for savings within the supply chain. DOE's production facility may not be able to produce components on a month to month basis and instead may have to produce components at an all or nothing method.

Limitations that were experienced within this research was the classification of true source data. The true source documents and time parameters for specific weapon systems and weapon components are classified and this research remained unclassified. Assumptions had to be made and the date ranges used could skew the actual cost savings or reduction of risk. Another assumption made was the quantity of weapons examined within the system of 1,550 includes all Air Force and Navy nuclear weapon systems while the data sources for the Bases only came from Air Force units. Further research could look at the ability of the Air Force and

Navy to adopt the same policies in order to minimize the variance experienced by the entire system.

Current developments being made within LLCs and tritium reservoirs may cause this research to be invalidated. The DOE is currently researching the capability to extend the life of components by changing the design of the system. This new design could allow the service life of the component to go beyond a point where the risk and cost savings could be arbitrary compared to the entire system.

Appendix: Summary Slide



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14. ABSTRACT

This research develops a method to measure the cost to society of current maintenance policy for the exchange of tritium based limited life components within nuclear weapons. The incentives for the Department of Energy and Department of Defense which causes either a substantial cost or substantial risk to be accepted by either Department. A simulation model is created to measure the current policy and compare it to different policies in order to recommend a policy that would minimize the cost to society. The measurement of the cost to society will offer decision makers insight into the ramifications of their decisions.

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